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54 Liquid ethylene-type random copolymer, process for production thereof, and use thereof.

57 A liquid ethylene-type random copolymer, useful as such or when hydrogenated as a synthetic lubricant oil, is characterized in that

(a) it has an ethylene unit content of from 10 to 85 mole% and an alpha-olefin unit content of from 15 to 90 mole%,

(b) it has a number average molecular weight (\bar{M}_n), measured by gel permeation chromatography, of from 3×10^2 to 1×10^4 ,

(c) it has a molecular weight distribution (\bar{M}_w/\bar{M}_n), determined by gel permeation chromatography, of not more than 2.5,

(d) it has a B value, defined by the following equation (I), as defined by the following equation (II)

$$B = \frac{P_{OE}}{2P_O \cdot P_E} \quad (I)$$

wherein P_E represents the molar fraction of the ethylene component in the copolymer, P_O is the molar fraction of the alpha-olefin component in the copolymer, P_{OE} is the molar fraction of alpha-olefin/ethylene chains in the total dyad chains,

$$1.05 \leq B \leq 2$$

(II),

(e) signals of $\alpha\beta$ and $\beta\gamma$ based on a methylene chain between two adjacent tertiary carbon atoms in the main chain of the copolymer are not substantially observed in the ^{13}C -NMR spectrum of the copolymer, and

(f) it has an iodine value of from 0 to 85.

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LIQUID ETHYLENE-TYPE RANDOM COPOLYMER, PROCESS FOR PRODUCTION
THEREOF, AND USE THEREOF

This invention relates to a liquid ethylene-type random copolymer, a process for its production and its use as a synthetic lubricant oil. More specifically, it relates to a liquid ethylene-type random copolymer having a narrow molecular weight distribution and a narrow composition distribution, a process for its production and its use as a lubricant oil.

It should be understood that the term "liquid ethylene-type random copolymer", as used in the present specification and claims, also denotes a waxy ethylene-type random copolymer.

Liquid ethylene/alpha-olefin copolymers, typically liquid ethylene/propylene copolymer, have been expected to find applications as synthetic lubricant oils or various resin modifiers. They are known to be produced by methods comprising copolymerizing ethylene with alpha-olefins in the presence of titanium-type catalysts composed of titanium compounds and organoaluminum compounds or vanadium-type compounds composed of vanadium compounds and organoaluminum compounds. Liquid ethylene/alpha-olefin copolymers produced in the presence of the titanium-type catalysts generally have poor randomness, broad molecular weight and composition distributions, and poor properties for use as synthetic lubricant oils. Liquid ethylene/alpha-olefin copolymers obtained in the presence of the vanadium-type catalysts have higher randomness, narrower molecular weight and composition distributions than the copolymers obtained with the titanium-type catalysts, and therefore have fairly improved properties for use as synthetic lubricant oils. It is still desired however to improve the quality of such copolymers for applications which must meet rigorous requirements.

Ethylene/alpha-olefin copolymers obtained with

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the vanadium-type catalysts are proposed, for example, in Japanese Patent Publications Nos. 21650/1972 and 42723/1972, and Japanese Laid-Open Patent Publications Nos. 117585/1982, 112809/1976, 65205/1973 and 35009/1985.

5 Japanese Patent Publication No. 21650/1972 and Japanese Laid-Open Patent Publication No. 117585/1982 both describe the utilization of liquid ethylene/alpha-olefin copolymers in synthetic lubricant oils. These copolymers, however, have the unsatisfactory properties mentioned above.

10 Japanese Laid-Open Patent Publication No. 112809/1976 discloses a viscosity index improver composed of an ethylene/propylene copolymer having a weight average molecular weight (\bar{M}_w)/number average molecular weight (\bar{M}_n) ratio of not more than 2.5 and an intrinsic viscosity of

15 0.4 to 1.5. However, the ethylene/propylene copolymers specifically described in the referential examples and working examples of this patent document are solid.

Japanese Patent Publication No. 42723/1972 and Japanese Laid-Open Patent Publication No. 65205/1973 describes

20 lubricant oil compositions comprising lubricant oils and solid ethylene/alpha-olefin copolymers having a crystallinity of 3 to 18% and a \bar{M}_w/\bar{M}_n of not more than 4. However, these solid ethylene/alpha-olefin copolymers cannot be used alone as synthetic lubricant oils. Japanese Laid-

25 Open Patent Publication No. 35009/1985 discloses ethylene/alpha-olefin copolymers having a \bar{M}_w/\bar{M}_n of less than 2 and a weight average molecular weight of about 2,000 to about 12,000,000, preferably about 10,000 to about 1,000,000, and a lubricant oil composition comprising a lubricant oil base

30 and such an ethylene/alpha-olefin copolymer. However, the ethylene/alpha-olefin copolymers specifically described in this patent document are high-molecular-weight solid copolymers. These solid ethylene/alpha-olefin copolymers, as stated above, cannot be used alone as synthetic lubricant

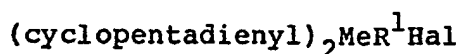
35 oils.

Catalysts comprising zirconium compounds and

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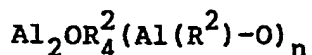
aluminos are disclosed in a series of prior art publications as new Ziegler-type olefin polymerization catalysts. But these publications fail to give any description which suggests liquid ethylene/alpha-olefin copolymers.

5 Japanese Laid-Open Patent Publication No. 19309/1983 describes a process which comprises polymerizing ethylene and at least one alpha-olefin having 3 to 12 carbon atoms at a temperature of -50°C to 200°C in the presence of a catalyst comprising a transition metal-containing compound represented by the following formula



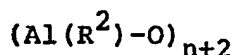
wherein R^1 is cyclopentadienyl, $\text{C}_1\text{-C}_6$ alkyl or halogen, Me is a transition metal, and Hal is halogen,

15 and a linear aluminosane represented by the following formula



wherein R^2 is methyl or ethyl and n is a number of 4 to 20,

20 or a cyclic aluminosane represented by the following formula

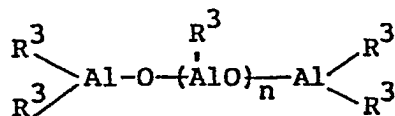


wherein R^2 and n are as defined.

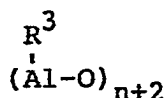
This patent document states that to control the density of the resulting polyethylene, ethylene should be polymerized in the presence of a small amount (up to 10% by weight) of an alpha-olefin having a somewhat long chain or a mixture of such alpha-olefins.

Japanese Laid-Open Patent Publication No. 95292/1984 describes a process for producing a linear aluminosane represented by the formula

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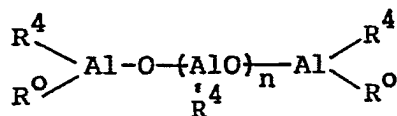
wherein n is 2 to 40 and R³ is a C₁-C₆ alkyl, and cyclic aluminoxanes of the formula



5 wherein n and R³ are as defined.

The patent document states that if ethylene is polymerized in the presence of a mixture of methylaminoxane produced by the process described in it with a bis(cyclopentadienyl) compound of titanium or zirconium, polyethylene is obtained
10 in an amount of at least 25 million grams/hour gram of transition metal.

Japanese Laid-Open Patent Publication No. 35005/-1985 discloses a process for producing an olefin polymerization catalyst which comprises reacting an aluminoxane
15 compound represented by the following formula



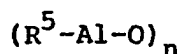
wherein R⁴ is C₁-C₁₀ alkyl, R⁰ is R⁴ or R⁴ and R⁰ together represent -O-,

with a magnesium compound, chlorinating the reaction product, and further treating the chlorination product with a
20 compound of Ti, V, Zr or Cr. The patent document states that the resulting catalyst is suitable for copolymerizing a mixture of ethylene and a C₃-C₁₂ alpha-olefin.

Japanese Laid-Open Patent Publication No. 35,006/1985 discloses a combination of (a) a mono-, di- or
25 tri-cyclopentadienyl of two or more different transition metals or a derivative thereof and (b) alumoxane (alumin-

oxane) as a catalyst for producing a blended polymer in a reactor. Example 1 of this patent document discloses that polyethylene having a number average molecular weight of 15,300, a weight average molecular weight of 36,400 and a propylene content of 3.4% was obtained by polymerizing ethylene and propylene using bis(pentamethylcyclopentadienyl)zirconium dimethyl and alumoxane as a catalyst. Example 2 of this patent document states that a blend of polyethylene and ethylene/propylene copolymer which has a number average molecular weight of 2,000, a weight average molecular weight of 8,300 and a propylene content of 7.1 mole% and consists of a toluene-soluble portion having a number average molecular weight of 2,200, a weight average molecular weight of 11,900 and a propylene content of 30 mole% and a toluene-insoluble portion having a number average molecular weight of 3,000, a weight average molecular weight of 7,400 and a propylene content of 4.8 mole% was obtained by polymerizing ethylene and propylene using bis(pentamethylcyclopentadienyl)zirconium dichloride, bis(methylcyclopentadienyl)zirconium dichloride and alumoxane. Likewise, Example 3 describes a blend of LLDPE and an ethylene/propylene copolymer which consists of a soluble portion having a molecular weight distribution (\bar{M}_w/\bar{M}_n) of 4.57 and a propylene content of 20.6 mole% and an insoluble portion having a molecular weight distribution of 3.04 and a propylene content of 2.9 mole%.

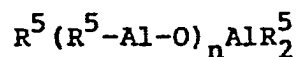
Japanese Laid-Open Patent Publication No. 35007/1985 discloses a process which comprises polymerizing ethylene alone or with an alpha-olefin having at least 3 carbon atoms in the presence of a catalyst comprising a metallocene and a cyclic alumoxane of the following formula



wherein R^5 is an alkyl group having 1 to 5 carbon atoms, and n is an integer of 1 to 20, or

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a linear alumoxane of the following formula



wherein R^5 and n are as defined.

The polymer obtained by this process has a weight average
5 molecular weight of about 500 to about 1,400,000 and a
molecular weight distribution of 1.5 to 4.0 as described in
this patent document.

Japanese Laid-Open Patent Publication No. 35008/
1985 describes that by using a catalyst system comprising
10 an alumoxane and at least two metallocenes, polyethylene or
a copolymer of ethylene and a $\text{C}_3\text{-C}_{10}$ alpha-olefin having
a broad molecular weight distribution is produced. This
patent document states that the above copolymer has a
molecular weight distribution of 2 to 50.

15 It is an object of this invention to provide a
novel liquid ethylene-type random copolymer.

Another object of this invention is to provide
a liquid ethylene-type random copolymer having a narrow
molecular weight distribution and a narrow composition
20 distribution.

Still another object of this invention is to
provide a liquid ethylene-type random copolymer having a
high viscosity index, a high ignition point and a low pour
point.

25 Yet another object of this invention is to pro-
vide a liquid ethylene-type random copolymer having ex-
cellent shear stability, oxidation stability and thermal
stability and giving excellent oil film strength.

A further object of this invention is to provide
30 a synthetic lubricant oil composed of the aforesaid liquid
ethylene-type random copolymer having excellent lubricant
oil properties.

A still further object of this invention is to
provide a liquid ethylene-type random copolymer which is

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also useful as a lubricant oil additive, a fuel oil additive or a modifier for polyolefins and rubbery polymers.

A y t further object of this invention is to provide a liquid ethylene-type random copolymer which has a double bond capable of reacting with maleic anhydride, etc. at the molecular chain ends and therefore permits easy modification according to various purposes.

Additional object of this invention is to provide a process for producing the aforesaid ethylene-type random copolymer.

Other objects of this invention along with its advantages will become apparent from the following description.

These objects and advantages of this invention are achieved in accordance with this invention by a liquid ethylene-type random copolymer consisting essentially of units derived from ethylene and an alpha-olefin having 3 to 20 carbon atoms, said copolymer being characterized in that

(a) it has an ethylene unit content in the range of 10 to 85 mole% and an alpha-olefin unit content in the range of 15 to 90 mole%,

(b) it has a number average molecular weight (\bar{M}_n), measured by gel permeation chromatography, of 3×10^2 to 1×10^4 ,

(c) it has a molecular weight distribution (\bar{M}_w/\bar{M}_n), determined by gel permeation chromatography, of not more than 2.5,

(d) it has a B value, defined by the following equation (I), within the range defined by the following equation (II)

$$B \equiv \frac{P_{OE}}{2P_O \cdot P_E} \quad \dots (I)$$

wherein P_E represents the molar fraction of the ethylene component in the copolymer, P_O is the molar fraction of the alpha-olefin component in

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the copolymer, P_{OE} is the molar fraction of alpha-olefin/ethylene chains in the total dyad chains,

$$1.05 \leq B \leq 2$$

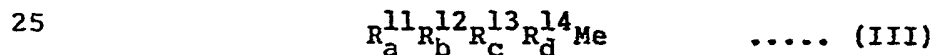
..... (II),

- 5 (e) signals of $\alpha\beta$ and $\beta\gamma$ based on a methylene chain between two adjacent tertiary carbon atoms in the main chain of the copolymer are not substantially observed in the ^{13}C -NMR spectrum of the copolymer, and
- 10 (f) it has an iodine value in the range of 0 to 85.

According to this invention, the liquid ethylene-type random copolymer of the invention can be produced in accordance with this invention by a process which comprises copolymerizing ethylene and an alpha-olefin having 3 to 20 carbon atoms in the presence of a catalyst comprising (A) a compound of a transition metal of Group IVb of the periodic table, and (B) an aluminoxane.

The compound (A) of a transition metal of Group IVb of the periodic table may, for example, be a compound of titanium (Ti), zirconium (Zr) or hafnium (Hf). Of these, Ti and Zr compounds are preferred, and the Zr compounds are most preferred.

These compounds are, for example, represented by the following formula (III)



wherein a, b, c and d are positive numbers and $a+b+c+d=4$, R^{11} represents an alkyl, alkenyl, cycloalkadienyl, aryl or aralkyl group, R^{12} is the same as R^{11} or represents a halogen atom, R^{13} and R^{14} are identical or different and each is the same as R^{12} or represents a hydrogen atom, and Me is Ti, Zr or Hf.

Example of the alkyl group in formula (III)

include methyl, ethyl, n-propyl, isopropyl, n-butyl, s c-butyl, tert-butyl, isobutyl and neopentyl groups.

Examples of the alkenyl group include isopropenyl and 1-butenyl groups.

5 Examples of the cycloalkadienyl group include cyclopentadienyl, methylcyclopentadienyl, ethylcyclopentadienyl, dimethylcyclopentadienyl, indenyl and tetrahydroindenyl groups.

10 Examples of the aryl group include phenyl and tolyl groups. Examples of the aralkyl group include benzyl and neophyl groups.

Example of the halogen atom are fluorine, chlorine and bromine atoms.

15 The compounds of formula (III) may, for example, be compounds of the following formula (III)-1



20 wherein e, f, g and h are positive numbers, and $e+f+g+h=4$, R^{15} represents a cycloalkadienyl group, and R^{16} and R^{17} are identical or different and each represents a cycloalkadienyl, aryl, aralkyl or alkyl group or a halogen or hydrogen atom.

Specific examples of the compounds of formula (III) including formula (III)-1 include

25 titanium compounds such as
bis(cyclopentadienyl)dimethyltitanium,
bis(cyclopentadienyl)diethyltitanium,
bis(cyclopentadienyl)diisopropyltitanium,
bis(cyclopentadienyl)dimethyltitanium,
bis(cyclopentadienyl)methyltitanium monochloride,
30 bis(cyclopentadienyl)ethyltitanium monochloride,
bis(cyclopentadienyl)isopropyltitanium monochloride,
bis(cyclopentadienyl)methyltitanium monobromide,
bis(cyclopentadienyl)methyltitanium monoiodate,

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bis(cyclopentadienyl)titanium difluoride,
bis(cyclopentadienyl)titanium dichloride,
bis(cyclopentadienyl)titanium dibromide, and
bis(cyclopentadienyl)titanium diiodate;
5 zirconium compounds such as
bis(cyclopentadienyl)dimethylzirconium,
bis(cyclopentadienyl)diethylzirconium,
bis(methylcyclopentadienyl)diisopropylzirconium,
bis(cyclopentadienyl)methylzirconium mono-
10 chloride,
bis(cyclopentadienyl)ethylzirconium monochloride,
bis(cyclopentadienyl)methylzirconium monobromide,
bis(cyclopentadienyl)methylzirconium monoiodate,
bis(cyclopentadienyl)zirconium difluoride,
15 bis(cyclopentadienyl)zirconium dichloride,
bis(cyclopentadienyl)zirconium dibromide,
bis(cyclopentadienyl)zirconium diiodate,
bis(cyclopentadienyl)zirconium monochloride
monohydride,
20 bis(cyclopentadienyl)zirconium monobromide mono-
hydride,
bis(cyclopentadienyl)methylzirconium hydride,
bis(cyclopentadienyl)ethylzirconium hydride,
bis(cyclopentadienyl)cyclohexylzirconium hydride,
25 bis(cyclopentadienyl)phenylzirconium hydride,
bis(cyclopentadienyl)benzylzirconium hydride,
bis(cyclopentadienyl)neopentylzirconium hydride,
bis(methylcyclopentadienyl)zirconium monochloride
monohydride, and
30 bisindenyl zirconium monochloride monohydride;
and
hafnium compounds such as
bis(cyclopentadienyl)dimethylhafnium,
bis(cyclopentadienyl)methylhafnium monochloride,
35 and
bis(cyclopentadienyl)hafnium dichloride.

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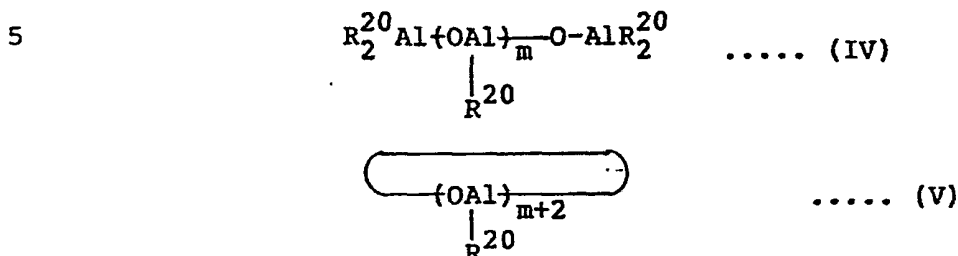
The transition metal compound may be used directly. Preferably, those transition metal compounds which are difficultly soluble in solvents such as toluene (for example, bis(cyclopentadienyl)zirconium monochloride monohydride) are used after they are contacted with organoaluminum compounds. This operation renders the sparingly solvent-soluble transition metal compounds readily soluble in solvents.

Specific example of the organoaluminum compounds to be contacted with the transition metal compounds include trialkyl aluminums such as trimethyl aluminum, triethyl aluminum and tributyl aluminum; trialkenyl aluminums such as triisoprenyl aluminum, dialkyl aluminum alkoxides such as dimethyl aluminum methoxide, diethyl aluminum ethoxide and dibutyl aluminum butoxide; alkyl aluminum sesquialkoxides such as methyl aluminum sesquimethoxide and ethyl aluminum sesquiethoxide; partially alkoxylated alkyl aluminums having the average composition of the formula $R^{18}_{2.5}Al(OR^{19})_{0.5}$ (wherein R^{18} represents an alkyl group or a halogen atom, and R^{19} represents an alkyl group); and partially halogenated alkyl aluminums, for example dialkyl aluminum halides such as dimethyl aluminum chloride, diethyl aluminum chloride and dimethyl aluminum bromide, alkyl aluminum sesquihalides such as methyl aluminum sesquichloride and ethyl aluminum sesquichloride, and alkyl aluminum dihalides such as methyl aluminum dichloride and ethyl aluminum dichloride.

Preferably, the reaction of the two compounds is carried out in a hydrocarbon solvent while shutting off light. The mole ratio of the organoaluminum compound and the zirconium compound (Al/Zr) is preferably from 0.5 to 30, more preferably from 1 to 20. The concentration of zirconium is preferably 0.001 to 1 mole, more preferably about 0.005 to 0.1 mole, per liter of the liquid phase. The reaction temperature is preferably 0 to 120°C, more preferably about 20 to 100°C.

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Specific examples of the aluminoxane (B) as an ingredient constituting the catalyst used in this invention are organoaluminum compounds represented by the following general formula (IV) or (V)



wherein R²⁰ represents an alkyl group, and m is preferably more than 20, especially preferably more than 25.

10 In these aluminoxanes, R^{20} is an alkyl group such as methyl, ethyl, propyl or butyl group, preferably the methyl and ethyl groups, especially preferably the methyl group. m is preferably more than 20, especially preferably at least 25, especially preferably 30 to 100.

15 The aluminoxanes may be prepared, for example, by
the following methods.

(1) A method which comprises adding a trialkyl aluminum in a suspension of a compound containing water of adsorption or a salt containing water of crystallization, for example, magnesium chloride hydrate, copper sulfate hydrate or aluminum sulfate hydrate, in a hydrocarbon medium, and reacting the compounds.

(2) A method which comprises reacting a trialkyl aluminum directly with water in a medium such as benzene, toluene, ethyl ether or tetrahydrofuran.

The method (1) is preferred. The alumionoxanes used in this invention may permissibly contain small amounts of organometallic components.

30 In the process of this invention, the starting material to be fed to the polymerization reaction system is a mixture of ethylene and an alpha-olefin having 3 to 20

carbon atoms. The content of ethylene in the starting material is usually 2 to 60 mole%, preferably 4 to 55 mole%, and the content of the alpha-olefin is usually 40 to 98 mole%, preferably 45 to 96 mole%.

5 Specific examples of the alpha-olefin having 3 to 20 carbon atoms used in the starting material in the process of this invention are propylene, 1-butene, 1-hexene, 4-methyl-1-pentene, 1-octene, 1-decene, 1-dodecene, 1-tetradecene, 1-hexadecene, 1-octadecene and 1-eicocene.

10 The polymerization reaction of the olefins in the process of this invention is usually carried out in a hydrocarbon solvent. Examples of the hydrocarbon solvent used for this purpose are aliphatic hydrocarbons such as butane, isobutane, pentane, hexane, octane, decane,
15 dodecane, hexadecene and octadecane; alicyclic hydrocarbons such as cyclopentane, methylcyclopentane, cyclohexane and cyclooctane; aromatic hydrocarbons such as benzene, toluene and xylene; and petroleum fractions such as gasoline, kerosene and light oils. The starting olefins may them-
20 selves serve as the hydrocarbon medium. Among these hydrocarbon media, the aromatic hydrocarbons and the starting olefins are preferably used in the process of this invention.

 The polymerization temperature in the process of
25 this invention is, for example, -50 to 200°C, preferably -30 to 100°C, especially preferably -20 to 80°C.

 The proportion of the transition metal compound (A) used in practicing the process of this invention is, for example, 10^{-8} to 10^{-2} gram-atom/liter, preferably 10^{-7}
30 to 10^{-3} gram-atom/liter, as the concentration of the transition metal in the polymerization reaction system. The proportion of the aluminosilicate (B) used is, for example, 10^{-4} to 10^{-1} gram-atom/liter, preferably 10^{-3} to 5×10^{-2} gram-atom, as the concentration of the aluminum atom in the
35 polymerization reaction system. The ratio of the aluminum atom to the transition metal in the polymerization

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reaction system is, for example, in the range of 25 to 10^7 , preferably 10^2 to 10^6 . The molecular weight of the copolymer can be controlled by using hydrogen, and/or by adjusting the polymerization temperature.

5 When the copolymerization reaction in the process of this invention is carried out in the absence of hydrogen, a liquid ethylene-type random copolymer having a high iodine value can be obtained. When it is carried out in the presence of hydrogen, a liquid ethylene-type random
10 copolymer having a low iodine value or an iodine value of substantially zero can be obtained.

 After the polymerization reaction by the process of this invention, the polymerization reaction mixture is worked up in a customary manner to give the liquid
15 ethylene-type random copolymer of the invention.

 When the liquid ethylene-type random copolymer having a high iodine value obtained by the aforesaid process is hydrogenated in the presence of a hydrogenating catalyst, a liquid ethylene-type random copolymer having a
20 lower iodine value or an iodine value of substantially zero can be obtained. Examples of the hydrogenating catalyst that can be used are metals of Group VIII of the periodic table such as iron, cobalt, nickel, rhodium, palladium and platinum. Of these, nickel is preferred. Raney nickel is
25 especially preferred. The hydrogenation reaction may be carried out in the presence or absence of solvent. Examples of the solvent are hydrocarbons such as pentane, hexane, heptane, octane, decane, cyclohexane, methyl-
cyclohexane and cyclooctane. The temperature in the hydrogenation reaction is, for example, 50 to 250°C , preferably 100 to 200°C . The hydrogenation reaction pressure
30 is, for example, in the range of 5 to $100\text{ kg/cm}^2\text{-G}$.

 The liquid ethylene-type random copolymer is substantially transparent at 25°C .

35 The liquid ethylene-type random copolymer of this invention has an ethylene unit content of 10 to 85 mole%,

preferably 20 to 80 mole%, especially preferably 30 to 70 mole%, and an alpha-olefin unit content of 15 to 90 mole%, preferably 20 to 80 mole%, especially preferably 30 to 70 mole%.

5 The liquid ethylene-type random copolymer of this invention has a molecular weight distribution (\bar{M}_w/\bar{M}_n), measured by gel permeation chromatography (GPC), of not more than 2.5, preferably not more than 2.2, especially preferably not more than 2. If the molecular weight dis-
10 tribution of the liquid ethylene-type copolymer is greater than 2.5, the liquid ethylene-type polymer has a lower ignition point and a higher pour point if its molecular weight remains the same.

 The molecular weight distribution is measured
15 as follows in accordance with Takeuchi, "Gel Permeation Chromatography" published by Maruzen Co., Ltd., Tokyo.

 (1) The GPC count of standard polystyrene (mono-disperse polystyrene made by Toyo Soda Co., Ltd.) of known molecular weight M is measured, and a calibration curve for
20 the molecular weight M versus the elution volume is drawn. The concentration of standard polystyrene at this time is adjusted to 0.02% by weight.

 (2) A gel permeation chromatograph of a sample polymer is taken by GPC measurement. From the calibration
25 curve mentioned in (1) above, the number average molecular weight \bar{M}_n and the weight average molecular weight \bar{M}_w of the sample are calculated. The \bar{M}_w/\bar{M}_n is thus obtained. The conditions for sample preparation and GPC measurement are as follows:

30 Sample preparation

 (a) The sample is put in an Erlenmeyer flask together with o-dichlorobenzene as a solvent so that its concentration becomes 0.1% by weight.

 (b) An antioxidant (2,6-di-tert-butyl-p-cresol)
35 is added in an amount of 0.05% by weight based on the polymer solution in the Erlenmeyer flask containing the sample.

(c) The Erlenmeyer flask is heated to 140°C, and the mixture is stirred for about 30 minutes to form a solution.

(d) The polymer solution is subjected to GPC.

5

GPC measurement

The measurement is conducted under the following conditions.

(a) Device: 150C-ALC/GPC made by Waters Co.

10

(b) Column: ZORBAX PSM Bimodal-s made by Du Pont Co.

(c) Amount of the sample: 200 microliters

(d) Temperature: 140°C

(e) Flow rate: 1 ml/min.

15 The liquid ethylene-type random copolymer of this invention has a number average molecular weight (\bar{M}_n), determined by GPC, of 3×10^2 to 1×10^4 , preferably 5×10^2 to 5×10^3 . The number average molecular weight is measured by GPC which is calibrated in advance using standard substances of known molecular weights (mono-

20 disperse polystyrene and squalane).

Furthermore, the liquid ethylene-type random copolymer of this invention has a B value, defined by the following equation (I), within the range defined by the following equation (II)

25

$$B \equiv \frac{P_{OE}}{2P_O \cdot P_E} \quad \dots\dots (I)$$

30

wherein P_E represents the molar fraction of the ethylene component in the copolymer, P_O is the molar fraction of the alpha-olefin component in the copolymer, P_{OE} is the molar fraction of alpha-olefin/ethylene chains in the total dyad chains [these molar fractions in equation (I) are calculated after excluding the terminal components],

$$1.05 \leq B \leq 2 \quad \dots\dots (II).$$

The B value is an index showing the state of distribution of the individual monomer components in the copolymer chain, and can be calculated from P_E , P_O and P_{OE} which are measured on the basis of G. J. Ray, *Macromolecules*, 10, 773 (1977), J. C. Randall, *Macromolecules*, 15, 353 (1982), J. Polymer Science, Polymer Physics Ed., 11, 275 (1973), and K. Kimura, *Polymer*, 25, 441 (1984).

As the B value is larger, the copolymer has higher alternateness between ethylene and alpha-olefin and a more uniform distribution of ethylene and alpha-olefin and a narrower composition distribution.

Preferably, the liquid ethylene-type random copolymer of this invention has the following B values.

When the copolymer has an ethylene content of not more than 50 mole%:-

$$1.0 + 0.3 \times P_E \leq B \leq 1/(1 - P_E),$$

more preferably

$$1.0 + 0.4 \times P_E \leq B \leq 1/(1 - P_E),$$

especially preferably

$$1.0 + 0.5 \times P_E \leq B \leq 1/(1 - P_E).$$

When the copolymer has an ethylene content of more than 50 mole%:-

$$1.3 - 0.3 \times P_E \leq B \leq 1/P_E,$$

more preferably

$$1.4 - 0.4 \times P_E \leq B \leq 1/P_E,$$

especially preferably

$$1.5 - 0.5 \times P_E \leq B \leq 1/P_E.$$

The B value was determined as follows:-

A sample is prepared by uniformly dissolving about 200 mg of the copolymer in 1 ml of hexachlorobutadiene in a sample tube having a diameter of 10 mm. The ^{13}C -NMR spectrum of the sample is usually measured under the following conditions.

Temperature: 120°C

Frequency: 25.05 MHz

Spectral width: 1500 Hz

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Filter width: 1500 Hz

Pulse repeating time: 4.2 sec

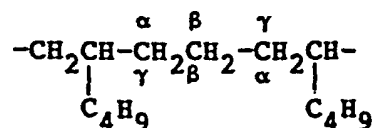
Pulse width: 7 usec

Integration cycles: 2000 to 5000

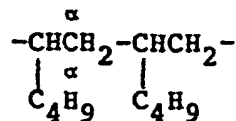
- 5 P_E , P_O and P_{OE} are determined from the spectrum, and the B value is calculated from these.

10 In the ^{13}C -NMR spectrum of the liquid ethylene-type random copolymer of this invention, signals of $\alpha\beta$ and $\beta\gamma$ based on a methylene chain between two adjacent tertiary carbon atoms in the main chain of the copolymer are substantially not observed.

15 For example, in the following bond of a copolymer of ethylene and 1-hexene, the three central methylene groups are at the positions of α , β , and γ from left when viewed from the left tertiary carbon derived from 1-hexene, and on the other hand, at the positions of α , β , and γ from right when viewed from the right tertiary carbon. Hence, the above bond unit contains methylene groups which give signals of $\alpha\gamma$ and $\beta\beta$, but contains no methylene group
20 which gives signals of $\alpha\beta$ and $\beta\gamma$.



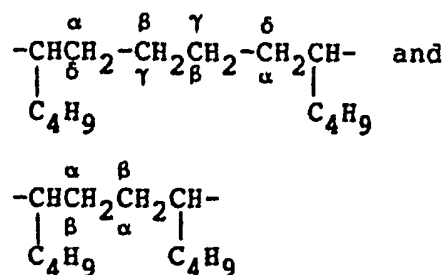
Likewise, in the following bond in which 1-hexenes are bonded by head-to-tail



- 25 only methylene groups which give signals of $\alpha\alpha$ exist, and there is no methylene group which gives a signal of $\alpha\beta$ and $\beta\gamma$.

On the other hand, the following bonds

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have methylene groups which give a signal of $\beta\gamma$ and a signal of $\alpha\beta$.

5 The liquid ethylene-type random copolymer of this invention has an iodine value of 0 to 85, preferably 0 to 50. When the iodine value of the liquid ethylene-type random copolymer of the invention is larger than 0, it is a
10 copolymer having a carbon-carbon unsaturated bond based on the ethylene units or alpha-olefin units at one end of the copolymer molecule units, or a mixture of a copolymer having a carbon-carbon unsaturated bond based on the ethylene units or the alpha-olefin units at one end of the copolymer molecule and a copolymer having no carbon-carbon
15 unsaturated bond at one end of the copolymer molecule. When the copolymer has an iodine value of zero, it has no unsaturated bond. For use as a lubricant oil, the liquid ethylene-type random copolymer of this invention conveniently has an iodine value of 0 to 0.3, preferably 0 to
20 0.2, especially preferably 0 to 0.1.

It is apparent from the foregoing description, in the liquid ethylene-type random copolymer of this invention, the direction of bonding of a monomer copolymerizable with ethylene is regular.

25 The liquid ethylene-type random copolymer of this invention usually has a viscosity index of 130 to 350, an ignition point of at least 240°C, and a pour point of not more than 0°C.

30 The liquid ethylene-type random copolymer of this invention has a narrow molecular weight distribution and a

- 20 -

composition distribution, and have various excellent properties required of lubricant oils.

When compared with copolymers obtained by using vanadium-type catalysts, the liquid ethylene-type random copolymer of this invention has nearly equal or narrower molecular weight and composition distributions; but it differs in the arrangement of ethylene and alpha-olefin in the main chain of copolymer and is superior in various properties which are considered necessary to lubricant oils.

When the liquid ethylene-type random copolymer of the invention is hydrogenated, there is obtained a hydrogenated polymer having a high viscosity index, a high ignition point, a low pour point, excellent shear stability, excellent oxidation stability, excellent thermal stability and high oil film strength. The hydrogenated polymer is used as a synthetic lubricant oil.

Furthermore, the liquid ethylene-type random copolymer of this invention can be easily modified according to various purposes since it has a double bond capable of reacting with maleic anhydride, etc. at the molecular chain ends.

The following examples specifically illustrate the present invention.

EXAMPLE 1

Preparation of a zirconium catalyst

Toluene (30 ml) and 2 millimoles of bis(cyclopentadienyl)zirconium monochloride monohydride were charged into a 100 ml glass flask thoroughly purged with nitrogen, and formed into a slurry. To the slurry was added dropwise at room temperature 20 millimoles of trimethyl aluminum diluted with toluene (1M solution). After the addition, the mixture was heated to 60°C and maintained at this temperature for 1 hour. The bis(cyclopentadienyl)zirconium monochloride monohydride dissolved in toluene, and the solution became dark red.

The above reaction was carried out while shutting off light.

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Preparation of aluminoxane

A 400 ml glass flask thoroughly purged with argon was charged with 13.9 g of magnesium chloride hexahydrate and 125 ml of toluene. After cooling the materials to 0°C, 250 millimoles of trimethyl aluminum diluted with 125 ml of toluene was added dropwise. After the addition, the temperature was raised to 70°C, and the mixture was maintained at this temperature for 96 hours. After the reaction, the reaction mixture was subjected to solid-liquid separation by filtration. Toluene was removed under reduced pressure from the separated liquid phase to give 7.3 g of aluminoxane as a white solid. The product has a molecular weight, determined from a freezing point depression in benzene, of 1910 and an η value of 31. At the time of polymerization shown below, the aluminoxane was used after again dissolving it in toluene.

Polymerization

A 2-liter continuous polymerization reactor was charged continuously with 1 liter/hr of purified toluene, 5 mg-atom/hr, as aluminum atom, of methylaluminoxane and 8×10^{-2} mg-atoms/hr, as zirconium atom, of the zirconium catalyst prepared above. Ethylene and propylene were simultaneously fed continuously into the reactor at a rate of 45 liters/hr and 240 liters/hr, respectively, and polymerized at 40°C and atmospheric pressure with a residence time of 1 hour under such conditions as to provide a polymer concentration of 65 g/liter. The resulting polymer solution was continuously withdrawn from the reactor, and the polymerization was stopped by adding a small amount of methanol. The polymer solution was washed four times with a large amount of water. Subsequent removal of toluene from the polymer solution gave a colorless transparent liquid polymer. The liquid polymer was dried at 130°C under reduced pressure (150 mmHg) for 12 hours. The liquid polymer had an ethylene content of 50 mole%, a number average molecular weight (\bar{M}_n) of 900, an (\bar{M}_w/\bar{M}_n) of 1.71, a

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B value of 1.30, a kinematic viscosity at 100°C of 28.1 cst, a viscosity index of 172, an ignition point of 261°C and an iodine value of 28. Signals based on $\alpha\beta$ and $\beta\gamma$

5 were not observed in the ^{13}C -NMR spectrum of the resulting polymer. The activity of the catalyst was 810 g of polymer/mg-atom of Zr.

EXAMPLES 2-9 AND COMPARATIVE EXAMPLES 1-2

Example 1 was repeated except that the conditions indicated in Table 1 were employed. Signals based on $\alpha\beta$
10 and $\beta\gamma$ were not observed in the ^{13}C -NMR spectra of the resulting polymers. The results are shown in Table 2.

COMPARATIVE EXAMPLE 3

The same continuous polymerization reactor as used in Example 1 was charged continuously with 2 liters/hr
15 of purified hexane, 48 mg-atom/hr, as aluminum atom, of ethyl aluminum sesquichloride and 8 mg-atom/hr, as vanadium atom, of vanadyl trichloride. Then, ethylene, propylene and hydrogen were simultaneously fed continuously into the reactor at a rate of 30 liters/hr, 30 liters/hr, and 100
20 liters/hr, respectively, and polymerized at 35°C under atmospheric pressure with a residence time of 0.5 hour under such conditions as to provide a polymer concentration of 49 g/liter. The reaction mixture was worked up in the same way as in Example 1. The ^{13}C -NMR spectrum of the
25 resulting liquid polymer showed signals based on $\alpha\beta$ and $\beta\gamma$.

Table 1

	Monomer 1		Monomer 2		Solvent (ℓ /hr)	Residence time (hr)	Polymerization temperature ($^{\circ}$ C)	Zr (mg-atom/ hr)	Al (mg-atom/ hr)	Polymer concentration (g/ ℓ)	Activity (g of polymer/ mg-atom of Zr)
	Type	Amount (ℓ /hr)	Type	Amount (ℓ /hr)							
Example 1	Ethylene	45	Propylene	240	1	1	40	0.08	5.0	65	810
2	"	50	"	"	"	"	"	"	"	67	840
3	"	45	"	"	"	"	"	0.02	"	75	3800
4	"	"	"	"	"	"	80	0.04	14.0	30	750
5	"	"	"	"	"	"	40	0.004	5.0	20	5000
6	"	"	1-Butene	250	"	"	"	0.08	"	57	710
7	"	200	1-Hexene	1	2	0.5	60	0.16	10.0	193	2400
8 (*)	"	45	propylene	240	1	1	40	0.02	5.0	32	1600
9	"	15	"	270	"	"	"	"	"	34	1700
Comparative Example 1	"	5	"	"	"	"	"	"	"	19	950
2 (**)	"	200	"	200	"	"	"	0.005	"	33	6600
3 (***)	"	30	"	30	2	0.5	35	8(VOCl ₂)	48	49	12

(*) H₂ 150 ℓ /hr was fed, (**) H₂ 60 ℓ /hr was fed, and (***) H₂ 100 ℓ /hr was fed; hexane was used as a solvent.

Table 2

	α -Olefin	Ethylene content (mole%)	\bar{M}_n	\bar{M}_w/\bar{M}_n	B value	Kinematic viscosity at 100°C (cst) 1)	Viscosity index 2)	Ignition point (°C) 3)	Iodine value 4)
Example 1	Propylene	50	900	1.17	1.30	28.1	172	261	28
2	"	53	1050	1.82	1.29	51.5	184	277	24
3	"	43	2400	1.79	1.25	423	214	302	11
4	"	63	530	1.65	1.27	7.6	171	242	48
5	"	49	3700	1.74	1.30	2050	320	307	6.9
6	1-Butene	55	1200	1.85	1.31	104	179	281	21
7	1-Hexene	59	960	1.68	1.32	37.5	181	266	26
8	Propylene	43	800	1.69	1.26	21.0	169	259	14
9	"	33	730	1.71	1.25	16.1	150	250	34
Comparative Example 1	"	6	690	1.77	1.05	15.5	75	241	36
2 (*)	"	87	5600	1.82	1.14	-	-	-	5
3	"	53	980	2.28	1.18	47.7	164	260	<0.1

1) Measured in accordance with JIS K-2283

2) Measured in accordance with JIS K-2283

3) Measured in accordance with JIS K-2265

4) Measured in accordance with JIS K-3342

(*) Waxy at room temperature

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EXAMPLE 10

Preparation of aluminoxane

Toluene (125 ml) and 37 g of $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$ were charged into a 400 ml flask fully purged with argon, and formed into a slurry. To the slurry was added dropwise at 0 to -5°C , 0.5 mole of trimethyl aluminum diluted with 125 ml of toluene. After the addition, the temperature was raised to 40°C , and the mixture was maintained at this temperature for 30 hours. Subsequently, the reaction mixture was subjected to solid-liquid separation by filtration. Toluene was removed from the separated liquid phase to obtain 15.2 g of aluminoxane as a white solid. The product had a molecular weight, determined from a freezing point depression benzene, of 1600, and a μ value of 26. For polymerization shown below, aluminoxane was used after again dissolving it in toluene.

Polymerization

A 1-liter continuous polymerization reactor was charged continuously with 500 ml/hr of purified toluene, 5.0 mg-atom/hr, as aluminum atom, of aluminoxane, and 5×10^{-3} mg-atom/hr, as zirconium atom, of bis(cyclopentadienyl)zirconium dichloride dissolved in toluene. Then, ethylene and propylene were simultaneously fed continuously into the reactor at a rate of 60 liters/hr and 140 liters/hr, respectively, and polymerized at 45°C under atmospheric pressure with a residence time of 1 hour under such conditions as to provide a polymer concentration of 71 g/liter. Water was added to the resulting polymer solution and deashing was carried out. Toluene was removed, and the residue was dried at 120°C under reduced pressure for 12 hours. The polymerization activity of the catalyst was 7100 g of polymer/mg-atom of Zr. The product was a liquid tacky polymer having an ethylene content of 62 mole%, an \bar{M}_n of 2800, a B value of 1.27, an iodine value of 9.1, an intrinsic viscosity of 0.19 dl/g and an \bar{M}_w/\bar{N}_n of 1.73. Signals based on $\alpha\beta$ and $\beta\gamma$ were not observed in the ^{13}C -NMR spectrum of the resulting polymer.

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EXAMPLE 11

Example 10 was repeated except that ethylene and propylene were continuously fed into the reactor at a rate of 40 liters/hr and 160 liters/hr, respectively, and polymerized under such conditions as to provide a polymer concentration of 37 g/liter. The polymerization activity of the catalyst was 3700 g of polymer/mg-atom of Zr. There was obtained a tacky liquid polymer having an ethylene content of 55 mole%, an intrinsic viscosity of 0.12 dl/g, an \bar{M}_n of 2000, an \bar{M}_w/\bar{M}_n of 1.60, a B value of 1.28 and an iodine value of 13. Signals based on $\alpha\beta$ and $\beta\gamma$ were not observed in the ^{13}C -NMR spectrum of the resulting polymer.

EXAMPLE 12

Example 10 was repeated except that ethylene and propylene were continuously fed into the reactor at a rate of 30 liters/hr and 170 liters/hr, respectively, and 1×10^{-2} mg-atom/hr, as zirconium atom, of bis(cyclopentadienyl)zirconium dichloride dissolved in toluene and polymerized under such conditions as to provide a polymer concentration of 48 g/liter. The polymerization activity of the catalyst was 2400 g of polymer/mg-atom of Zr. There was obtained a tacky liquid polymer having an ethylene content of 51 mole%, an intrinsic viscosity of 0.08 dl/g, an \bar{M}_n of 1500, an \bar{M}_w/\bar{M}_n of 1.53, a B value of 1.28 and an iodine value of 17. Signals based on $\alpha\beta$ and $\beta\gamma$ were not observed in the ^{13}C -NMR spectrum of the resulting polymer.

EXAMPLE 13

Example 12 was repeated except that ethylene and propylene were continuously fed into the reactor at a rate of 40 liters/hr and 160 liters/hr, respectively, and polymerized at 70°C under such conditions as to provide a polymer concentration of 24 g/liter. The polymerization activity of the catalyst was 1200 g of polymer/mg-atom of Zr. There was obtained a liquid polymer having an ethylene content of 65 mole%, an \bar{M}_n of 1300, an \bar{M}_w/\bar{M}_n of 1.59, a B value of 1.26, an iodine value of 19, and an intrinsic

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viscosity of 0.07 dl/g. Signals based on $\alpha\beta$ and $\beta\gamma$ were not observed in the ^{13}C -NMR spectrum of the polymer.

EXAMPLE 14

Example 12 was repeated except that ethylene and
5 1-butene were continuously fed at a rate of 40 liters/hr and 160 liters/hr, respectively, at 60°C under such conditions as to provide a polymer concentration of 44 g/liter. The polymerization activity of the catalyst was 2200 g of polymer/mg-atom of Zr. There was obtained a tacky liquid
10 polymer having an ethylene content of 60 mole%, an \bar{M}_n of 2300, an \bar{M}_w/\bar{M}_n of 1.82, a B value of 1.30, an iodine value of 11, and an intrinsic viscosity of 0.14 dl/g. Signals based on $\alpha\beta$ and $\beta\gamma$ were not observed in the ^{13}C -NMR spectrum of the polymer.

15 EXAMPLE 15

A 2-liter SUS stainless steel autoclave fully
purged with nitrogen was charged with 500 ml of purified
toluene and 500 ml of propylene at 20°C . Subsequently, 10
mg-atom, as aluminum atom of the aluminosilane synthesized in
20 Example 10, and 0.015 mg-atom, as zirconium atom of bis-
(cyclopentadienyl)zirconium dichloride dissolved in toluene
were introduced under pressure together with ethylene. The
monomers were then polymerized at 30°C for 2 hours under a
partial ethylene pressure of 0.5 kg/cm^2 . The polymeriza-
25 tion was stopped by adding a small amount of ethanol, and
then the unreacted propylene and ethylene were purged. The
polymer was obtained as a solution in toluene. Hydro-
chloric acid was added to the polymer solution, and the
catalyst residue was removed. The solution was washed with
30 water, and toluene was removed. The residue was then dried
to give a liquid polymer having an ethylene content of 41
mole%, an \bar{M}_n of 1600, an \bar{M}_w/\bar{M}_n of 1.96, a B value of 1.28,
an iodine value of 16, and an intrinsic viscosity of 0.09
dl/g. The polymerization activity of the catalyst was 7500
35 g of polymer/mg-atom of Zr. Signals based on $\alpha\beta$ and $\beta\gamma$
were not observed in the ^{13}C -NMR spectrum of the polymer.

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EXAMPLE 16

Preparation of alumoxane

Aluminoxane was synthesized in the same way as in Example 10 except that 39 g of $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$ was used and reacted at 40°C for 6 days. The resulting aluminoxane had a molecular weight, determined from a freezing point depression in benzene, of 2800 and a \bar{m} value of 46.

Polymerization

The same polymerization as in Example 12 was repeated except that the polymerization was carried out under such conditions as to provide a polymer concentration of 59 g/liter. The polymerization activity of the catalyst was 3000 g of polymer/mg-atom of Zr. There was obtained a liquid polymer having an ethylene content of 49 mole%, an \bar{M}_n of 1400, an \bar{M}_w/\bar{M}_n of 1.50, a B value of 1.29, an iodine value of 18 and an intrinsic viscosity of 0.08 dl/g. Signals based on $\alpha\beta$ and $\beta\gamma$ were not observed in the ^{13}C -NMR spectrum of the polymer.

APPLICATION EXAMPLE 1

A 2-liter stainless steel autoclave was charged with 1 liter of cyclohexane, 100 g of the liquid polymer obtained in Example 1 and 4 g of a nickel catalyst (N-103, a product of Nikki Chemical Co.), and the polymer was hydrogenated at 150°C for 3 hours under a hydrogen pressure of $25 \text{ kg/cm}^2\text{-G}$. After the reaction, cyclohexane was removed, and the product was dried at 130°C under reduced pressure (150 mmHg) for 12 hours. The resulting liquid polymer had a kinematic viscosity at 100°C of 28.8 cst, a viscosity index of 171, an ignition point of 264°C , a pour point of -37.5°C , a load carrying capacity of 7.5 kg/cm^2 and an iodine value of less than 0.1.

APPLICATION EXAMPLES 2-4

The liquid polymers obtained in Examples 2 to 7 were respectively hydrogenated in the same way as in Application Example 1. The results are shown in Table 3.

Table 3

Application Example	Polymer used (by Examples)	Kinematic viscosity at 100°C (cst) 1)	Viscosity index 2)	Ignition point (°C) 3)	Pour point (°C) 4)	Load carrying capacity (kg/cm ²) 5)	Iodine value 6)
1	1	28.8	171	264	-37.5	7.5	<0.1
2	2	50.2	182	281	-35.0	8.0	"
3	3	420	214	305	-10.0	-	"
4	4	7.5	172	247	-55.0	5.5	"
5	5	2090	318	310	0	-	"
6	6	100	177	285	-32.5	8.0	"
7	7	38.1	181	271	-37.5	8.0	"

The above properties were measured in accordance with the following test methods.

- 1) JIS K-2283
- 2) JIS K-2283
- 3) JIS K-2265
- 4) JIS K-2269
- 5) JIS K-2519
- 6) JIS K-3342

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EXAMPLES 17-18

Ethylene and propylene were copolymerized in the same way as in Example 1 except that instead of the zirconium catalyst used together with aluminoxane, bis(cyclopentadienyl)hafnium dichloride (Example 17) or bis(cyclopentadienyl)titanium dichloride (Example 18) was used. The polymerization conditions and the results are shown in Table 4.

Table 4

Example			17	18
Monomer 1	Type		Ethylene	Ethylene
	Amount (ℓ/hr)		45	45
Monomer 2	Type		Propylene	Propylene
	Amount (ℓ/hr)		240	240
Solvent (ℓ/hr)			1	1
Residence time (hr)			1	1
Polymerization temperature (°C)			40	40
Catalyst	Transition metal	Type	Hf	Ti
		Amount (mg-atom/hr)	0.20	0.50
	Al (mg-atom/hr)		5.0	2.0
Polymer concentration (g/ℓ)			16	8
Activity (g of polymer/mg-atom of metal)			80	16
Ethylene content (mole%)			54	47
\overline{M}_n			810	730
$\overline{M}_w/\overline{M}_n$			2.05	2.34
B value			1.24	1.22
Kinematic viscosity at 100°C (cst)			23.2	15.5
Viscosity index			165	159
Ignition point (°C)			260	258
Iodine value			31	35

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CLAIMS

1. A liquid ethylene-type random copolymer consisting essentially of units derived from ethylene and an alpha-olefin having 3 to 20 carbon atoms, said copolymer being characterized in that

5 (a) it has an ethylene unit content of from 10 to 85 mole% and an alpha-olefin unit content of from 15 to 90 mole%,

(b) it has a number average molecular weight (\bar{M}_n), measured by gel permeation chromatography, of from 3×10^2 to 1×10^4 ,

10 (c) it has a molecular weight distribution (\bar{M}_w/\bar{M}_n), determined by gel permeation chromatography, of not more than 2.5,

15 (d) it has a B value, defined by the following equation (I), as defined by the following equation (II)

$$B \equiv \frac{P_{OE}}{2P_O \cdot P_E} \quad \text{..... (I)}$$

wherein P_E represents the molar fraction of the ethylene component in the copolymer, P_O is the molar fraction of the alpha-olefin component in the copolymer, P_{OE} is the molar fraction of alpha-olefin/ethylene chains in the total dyad chains,

$$1.05 \leq B \leq 2 \quad \text{..... (II)},$$

25 (e) signals of $\alpha\beta$ and $\beta\gamma$ based on a methylene chain between two adjacent tertiary carbon atoms in the main chain of the copolymer are not substantially observed in the ^{13}C -NMR spectrum of the copolymer, and

(f) it has an iodine value of from 0 to 85.

2. A copolymer according to claim 1 which has an ethylene unit content of from 20 to 80 mole% and an alpha-olefin unit content of 20 to 80 mole%.

30

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3. A copolymer according to claim 2 which has an ethylene unit content of from 30 to 70 mole% and an alpha-olefin unit content of from 30 to 70 mole%.
4. A copolymer according to any one of the preceding claims which has a number average molecular weight (b) of from 5×10^2 to 5×10^3 .
5. A copolymer according to any one of the preceding claims which has a molecular weight distribution (c) of not more than 2.2.
- 10 6. A copolymer according to any one of the preceding claims which has an ethylene unit content of not more than 50 mole% and a B value (d) defined by the formula
- $$1.0 + 0.3 \times P_E \leq B \leq 1 / (1 - P_E).$$
7. A copolymer according to any one of claims 1 to 5 which has an ethylene content of more than 50 mole% and a B value (d) defined by the equation
- $$1.3 - 0.3 \times P_E \leq B \leq 1 / P_E.$$
8. A copolymer according to any one of the preceding claims which has an iodine value of from 0 to 50.
- 20 9. A process for producing a liquid ethylene-type random copolymer according to any one of the preceding claims, which comprises copolymerizing ethylene and an alpha-olefin having 3 to 20 carbon atoms in the presence of a catalyst comprising a compound of a transition metal of Group IVb of the periodic table and an aluminoxane.
- 25 10. A process according to claim 9 wherein the transition metal is titanium, zirconium or hafnium.
11. A process according to claim 10 wherein the compound of the transition metal is represented by the following formula (III)
- 30



wherein a, b, c and d are positive numbers and $a+b+c+d=4$, R^{11} represents an alkyl, alkenyl, cycloalkadienyl, aryl or aralkyl group, R^{12} represents an alkyl, alkenyl,

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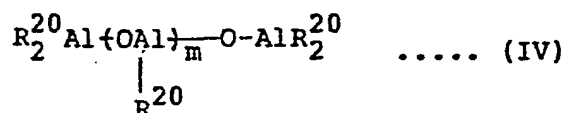
cycloalkadienyl, aryl or aralkyl group or a halogen atom, R^{13} and R^{14} are identical or different and each represents an alkyl, alkenyl, cycloalkadienyl, aryl or aralkyl group or a hydrogen or halogen atom and Me is Ti, Zr or Hf.

- 5 12. A process according to claim 9 or 10 wherein the compound of the transition metal is represented by the following formula (III-1)

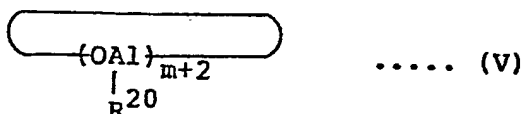


- 10 wherein e, f, g and h are positive numbers, and $e+f+g+h=4$, R^{15} represents a cycloalkadienyl group, and R^{16} and R^{17} are identical or different and each represents a cycloalkadienyl, aryl, aralkyl or alkyl group or a halogen or hydrogen atom.

13. A process according to any one of claims 9 to 12
15 wherein the aluminoxane is a compound represented by the following formula (IV) or (V)



wherein R^{20} represents an alkyl group and m is more than 20, or



20

wherein R^{20} and m are as defined above.

14. A process according to any one of claims 9 to 13 wherein the copolymerization reaction is carried out in a hydrocarbon medium.

- 25 15. A process according to any one of claims 9 to 14 wherein the copolymerization reaction is carried out at a temperature of from -50°C to 200°C .

16. A process for producing a hydrogenated liquid
30 ethylene-type random copolymer, which process comprises hydrogenating a liquid ethylene-type random copolymer as

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claimed in any one of claims 1 to 8 or which has been produced by a process as claimed in any one of claims 9 to 15.

17. A process according to claim 16, wherein
5 hydrogenation is effected on a said liquid ethylene-type random copolymer having an iodine value of not more than 80 such as to obtain a hydrogenated polymer having an iodine value of from 0 to 0.3.

18. Use as a synthetic lubricant oil of a liquid
10 ethylene-type random copolymer as claimed in any one of claims 1 to 8 or which has been produced by a process as claimed in any one of claims 9 to 15 or of a hydrogenated liquid ethylene-type random copolymer which has been produced by a process as claimed in claim 16 or 17.